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ABSTRACT

As part of a study on the impact of automation on training, extensive interviews were conducted at two of Fiat's plants, Termoli and Casino, Italy. Termoli, a plant built in the mid-1980s with automation in mind, production of engines and gear boxes was very much integrated by automation devices. Casino produced some individual components but was basically an assembly plant with the highest level of integrated automation in Europe. Data on personnel at both plants confirmed that the majority of workers were not skilled, but a relatively high number of skilled workers were necessary for automation. New training needs arose from the complexity of the new equipment, configuration of the machines, and division of work among workers. Skill requirements were also defined by production goals--flexibility, efficiency, quality, and a better and safer work environment. Three of the jobs most affected by automation were operators, maintenance crew members, and line technicians. Training took place before operations began; a significant portion consisted of formal courses. The study also explored why and how modern manufacturing firms were becoming more learning- than technology-intensive organizations. Formal training was found to be only part of what was required; a great amount of learning could occur only on the job. Learning for high tech operations was shown to be acquired through carefully designed and orchestrated organizational practices. (13 references) (YLB)

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The learning basis of automated factories: The case of FIAT

by João Batista Araujo e Oliveira

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by João Batista Araujo e Oliveira

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Training Policies Branch
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Contents

Foreward v

Introduction vii

I. The Termoli and Casino Plants 1

II. Skill requirements 5

III. Informal Learning 17

A. An emerging learning-intensive organisation 22

References 27

Foreword

The present paper is part of a study on the impact of automation on training. The opinions expressed here are the author's sole responsibility. The present paper is part of an ongoing study being conducted by the ILO on the effects of automation on training requirements for middle-level technical workers. For practical reasons, the study concentrates on the skills required of middle-level technical workers. Thus, it excludes engineers with diplomas and the traditional skilled and semi-skilled professionals. The terms technician or technologist are avoided for two major reasons. Firstly because they have different meanings in different industries and countries. Secondly because technology affects all workers, and technical knowledge becomes a major requirement throughout the high tech organisation - and the high tech society.

Four countries were included in the sample. This being an exploratory study, no attempt was made to draw up a representative sample. Two were NICs (Newly Industrialised Countries) representing two different stages of industrial and technological development in two very different geo-economic locations, Brazil and Singapore. The other two are developed countries. In France, it was possible to access a varied typology of high tech firms, with different types of products and varied levels of automation. Italy was chosen because access to FIAT allowed us to illustrate the more advanced type of a fully automated factory in the most dynamic sector.

Italy and FIAT were chosen both by design and serendipity. Looking retrospectively, there are good reasons to justify the choice and to take advantage of it. As Porter (1990, p. 438) puts it, "the industrial success of Italy can be traced to process breakthroughs and the application of modern flexible manufacturing technology to traditional products". Italy's four major industrial groups, FIAT, de Benedetti, Ferruzi and Pirelli are certainly among the world's more technologically advanced firms, even though they characterise a country with a few, strong oligopolies and not many really big industries. Yet, Italy is one of Europe's major suppliers of automated manufacturing devices and control systems for production machinery. The fact that Italy provides little formal pre-employment training has no vocational system comparable to what is found in German-speaking countries or France, for that matter, makes their coping strategies even more interesting from the perspective of other countries with less sophisticated training systems.

FIAT is possibly not the best representative of the auto manufacturing industry in Europe, but it certainly has a major presence in the small car market, representing 35% of the European market and 85% at home. FIAT represents 50% of the increasingly competitive automotive market in Italy (DRI, 1987).

FIAT's massive entry into the world of high-tech, since the mid 70s, represented a response to the Italian situation and to the new type of competition that was shaping up. Technology was adopted to simultaneously deal with the threats of the time: labour unrest in an extremely complex environment of labour relations; wage escalation at home coupled with prevailing low wages from NICs; a rising lira that made products even less competitive in foreign markets; and the increasing trend towards the globalisation of world markets, and, of course, the growing demand for differentiated products.

The fact that high tech was implemented, succeeded, and contributed to improve FIAT's and Italy's position is even more important when it is analysed against the characteristics and shortcomings of the national context in which it ocurred. The more a country faces different problems such as labour relations, firm location,

complex relationships with suppliers and lack of experience, the more creative can be its responses, and the more we can learn form its experience. After all, the new entrants into the high tech world will face more, not less constraints than FIAT did in Italy.

The present study was primarily based on readings and information collected in a number of interviews at 6 FIAT locations (headquarters, ISVOR - FIAT's training institution, the Agnelli Foundation, the automated plants at Termoli and Casino and the plant in Brazil). Over 60 individual and group interviews were made, which included senior officials, engineers, technicians, operators, non-skilled workers, as well as trainers and human resource specialists.

An attempt is made in this case study to understand how automation creates training needs, and how training needs are dealt with. As illustrated here, skill requirements brought in by new work technologies are affected far beyond the training system, and are leading to a profound transformation in the way the jobs are designed and in the way people are managed. After briefly introducing FIAT's corporate strategies regarding automation, we describe the basic characteristics of two plants located at Termoli and Casino. Then we discuss the nature of the skills required at these plants to deal with the new work technologies by exploring two alternative approaches: the training needs derived form the physical technologies themselves and those derived from the actual configuration of the work put in place to operate with these new work tools. This analysis allows us to highlight the strong interaction between training needs and other organisational design variables, which, in this case, contributed to the emergence of new occupational roles. As some workers were more affected by new work technologies than others, we concentrate our analysis on the operators, maintenance specialists and the new professional figure of the line technician. We then move on to analyse the massive training response deployed by the corporation as a whole, by its newly created training institute, ISVOR, and by the individual plants. We also discuss what kinds of training are provided, what is taught, how much it costs, and how training is distributed.

Besides and beyond investing in formal training, automation led FIAT to reorganise the workplace, the work relations and the conditions of work. Technologies require people to learn and to teach on a daily basis. For most of the categories of workers analysed in this case, working and learning are becoming synonymous. The explosion of informal learning and its organisational consequences constitute the focus of the last part of the paper. It is suggested that more than capital or technology intensive, corporations like FIAT are becoming learning-intensive firms.

In different moments of our history, learning and schooling were closely attached to specific social actors: the church, the bureaucracy, the bourgeoisie. Who would be educated, how, and what would be the curricula were dictated by the values and needs of these groups. Now, industry is coming into the forefront, and it is in want of knowledge. In a changing world in which learning occupies an increasingly prominent place, it is not a coincidence that learning in industry is also becoming increasingly important and creating new challenges for the education and training systems. More than merely creating these new demands, the modern corporation is itself becoming a learning organisation.

Introduction

Automation of production started as a part of FIAT's overall business strategy developed since the early 70's. It came as a response to societal, economic and technological changes. Italian society was in a period of extreme social unrest, corporations suffered from a bad image, relationships with unions and workers on the shop floor were at their lowest ebb. The first oil crisis was only starting to make its effects known - and the worst had not yet come for the economy in general and for the automobile industry in particular. But there were strong signs that productivity had to be improved and that major changes would be required in the way corporations were managed and production structured. The major blow, however, came from the East. Japanese firms were just starting to make defect-free cars by using a few management innovations and by incorporating automation techniques in the manufacturing process. Not only could they produce higher quality cars - but by using flexible manufacturing systems of production they could tailor their products to satisfy the increasingly diversified demands of the clients.

The decision to introduce automation into FIAT's manufacturing operations was taken in the early 70's. Figure 1 below gives a simplified account of some of the major steps taken by the FIAT automotive group.

Figure 1

Chronology of Automation

Early 70's	Societal, economic, technological changes
1976	Introduction of Robogate
1980	Reorganisation of FIAT's corporate structure
	Decision to automate the Termoli plan
	Creation of ISVOR - FIAT's institute for high tech training
early 80's	Dissemination of automation to other plants
1982	Beginning of training for Termoli
1984	Automation of engine production, Termoli
1985	Automation of gear box production, Termoli
85/86	Reorganisation of Termoli - integrated factory
87/88	Reconversion of Casino - no interruption of operations
1989	Synthesis of automation of Casino (Fully Automated Manufacturing)
	Reorganisation
1990	New system (Jove) being implemented to replace Robogate

Even though it makes a long story very short, Figure 1 illustrates a number of very important characteristics of the automation process. Automation was introduced progressively - and relatively slowly. This policy was intentional, as it allowed the corporation to learn from its own experiences. It started with decentralised experiences with the use of Robogate since 1976, as well as with the use of fixed automation. Automated-controlled production was progressively transmitted from one production line to the next, from plant to plant, thus avoiding major mistakes and economising on learning time,

systems development, and training. To some extent, the slow pace of introducing technology was also due to other factors, such as lengthy labour negotiations and the lack of necessary skills in the labour force.

But the rhythm of this process was now uniform. Even though the overall process might seem long - we are talking about 20 years of automation - it accelerated, particularly after 1985. The actual automation of individual plants was very quick, and in the case of the Casino plant, amasingly so. It took slightly over one year for the Casino plant to reconvert its conventional plant to an automated one, and another year and a half to consolidate Europe's first fully automated automotive assembly plant.

Another important point illustrated by Figure 1 is the relationships between automation and reorganisation of the factories. The FIAT group, as a whole, was reorganised in 1980, before factory automation was implemented on a large scale. This reorganisation responded to the new business strategies, which included decisions to introduce massive automation at Casino and Termoli. At that time the corporation also decided to consolidate its three training institutes into a new one, ISVOR, which played a major role on the activities to be discussed in the present paper. The characteristics of the Institute itself are analysed in another paper by the author (Oliveira, 1991a).

But most interesting for our purposes is the relationship between automation and organisational reform at the plant sites. Both in Termoli and Casino automation came first - sometimes overlapping with traditional production lines - and once in place, reorganisation was introduced. This approach is to be contrasted with the typical pattern of modernisation of the Japanese industry (Hoffman and Kaplinsky, 1988), where the changes in organisation of production (Just in Time, Kanban, flat hierarchies, etc.) usually preceded the physical modernisation and automation of plants. In the case of FIAT, the driving force was the machinery and automation, which gave the firm control of the shop floor and generated new conditions for a new style of management and work organisation. In the turbulent industrial relations environment of the 70s, technology was a disequilibrium factor in the vector of forces, and devolved to FIAT's management the power to take initiatives concerning work organisation. The successful experience of introducing automation in the 70s was repeated when introducing the highly flexible, integrated manufacturing systems characteristic of the high tech plants studied here. Organisational change came later, but not late, since otherwise the firm could not benefit from the flexibility made possible by the new work technologies.

Figure I also illustrates another intriguing characteristic of modernisation processes: even in a highly mobile and changing sphere like computer software, Robogate, the backbone of FIAT's production system management stayed in place for over 15 years. Robogate was developed by FIAT in the mid 70s and has been partially upgraded throughout the 80s, until a new replacement was conceived, which started being implemented in the early 1990s. Even though more updated technologies became available in the meantime, the sunk costs associated with having Robogate in place prevented any attempts to substitute it. By maintaining Robogate in the centre of its automated process FIAT allowed itself the necessary time to accumulate and transfer experience across its plants, while ensuring compatibility throughout its production lines. This is to be contrasted with the erratic changes of configurations and systems associated with many processes of technology introduction which are led by technological, rather than by overall organisational concerns.

Overall, the introduction of automation in FIAT's automotive plants illustrates a continuous process of continuity and change. The old coexists with the new - but in no way precludes the new from taking its place. Old production lines continued to operate side by side with the new ones. Plants were reconverted from old to new production lines, without stopping production. Systems were introduced and changed - but not so quickly as to destroy the learning accumulated through the earlier versions. Organisational change comes as a result of new organisational practices being field tested, and only then they are adopted to replace old ones.

Training - the central concern of this paper - played a central role both in the strategic plans and in the implementation of automated production. The creation of ISVOR - a key actor in this process - also illustrates the process of continuity and change referred to previously. There was a rupture in the sense that three conventional training institutions were abolished and replaced by a financially autonomous and self-supported training centre. Less than ten years after its incorporation, ISVOR has become Italy's most advanced training centre on new production technologies. Old training policies and practices were completely overhauled. Yet, ISVOR represents FIAT's tradition of training, inaugurated in 1922 with the creation of the Giovanni Agnelli School for Apprentices. From the past, ISVOR also inherited most of its personnel as well as the intimacy and the direct access to all its clients within the FIAT corporation - and these are undoubtedly its major assets.

I. The Termoli and Casino plants

The present paper is based on extensive interviews conducted at two of FIAT's plants, Termoli and Casino. These plants bear many characteristics in common, as well as many differences. They were carefully chosen, as they represent two different scales of automation - and certainly the most complex attempts of manufacturing automation undertaken so far by FIAT. We briefly sketch the characteristics, similarities and differences between these two plants.

Termoli essentially produces engines and gear boxes. The new plant was built in the mid 80s with automation in mind. Workers from the old existing facilities were retrained and reallocated to the new factory. The factory works in three shifts and average daily output includes 3,200 gear boxes and 3,000 engines, which can be produced according to 65 different specifications.

Production is very much integrated by automation devices. In the engine unit, for example, parts arrive throughout the day, under the Just-in-Time system. Most of the parts are quality certified at the suppliers' sites and are delivered directly into the small buffer stocks located next to the production lines where they are going to be used. Some components are manually loaded onto the conveyor belts - others are charged by mechanical or electro-mechanical means. For a family of engines, work stations are disposed sequentially, one machine next to the other, each performing one type of operation. Buffer stocks between each operation are kept to a minimum - in most cases they are sufficient for 20-30 minutes. This is the maximum time which an individual robot or machine can be stopped for adjustment, retooling or maintenance without disrupting the flow of production and affecting the expected daily output. In some cases alternative routing of operations is possible. If longer stoppages are necessary - for lack of a given part, for example - other versions of a model can be produced. Most of the controls and retooling activities are performed automatically - but both require varying degrees of programming. In addition, visual and manual inspection are performed at all times. Sample tests are also performed on a routine basis to check whether the machines are operating within acceptable margins of tolerance.

Figure 2 gives an account of the total manpower in the two plants at Termoli and Casino, as well as the breakdown of the major functions involved. In the case of Termoli, production more than doubled with virtually the same workforce. In fact, the workforce had already been streamlined in the previous generation of organisational reforms, when mechanisation and fixed automation were first introduced. The new plant, however, required changes in the profile of some workers, particularly in number and qualification of technicians, which will be discussed later in more detail.

Figure 2

	Termoli	Casino
Total staff	3.064	7.000
Managers	6	20
White collar	425	780
Blue collar of which	2.633	6.200
Maintenance	413	900
Operators	576	350
Quality control	297	200

Casino produces some individual components but is basically an assembly plant - with the highest level of integrated automation in Europe. There, an average of 1,400 cars (two basic models) are assembled daily. No two cars are necessarily identical - they are produced to meet the specifications of the dealers. Responding to individual preferences of consumers requires a sophisticated system of orders, parts management, parts supply, production and delivery. It also requires hundreds of sensor mechanisms (tag readers and PLCs) spread throughout the production line, to identify each final product and ensure that each part, colour or type of finishing belongs to that specific car. Figure 3, below, gives an account of the layers of automation involved in the assembly plant at Casino.

Figure 3
Levels of automation, Casino

Systems	Functions
Giove system	Overall software control (replacing Robogate)
5 VAC computers	Receive & analyse information issue production orders
67 Mini computers	Assembly & diagnosis
442 Tag readers	Read car-specific instructions
791 PLCs	Read part-specific instructions

More than the level of automation, it is the level of informatisation that characterises the brisk rhythm and the high level of complexity and interdependence of the manufacturing operations.

The best and probably most familiar image to most readers which might help in understanding the complexity of these interactions can be illustrated by modern photocopying machines. The reader can easily imagine the operation of one machine - and the several different types of operations required for very simple copying activities: feeding paper of different sizes; changing toner cartridge; pushing buttons to determine number of copies, or the intensity of ink; manual or automatic feeding; one or two sides; stapling or not stapling. Problems may arise for a variety of reasons: insufficient or wrong instructions; paper jam; lack of paper; lack of toner, and so on. Each of these very simple problems causes small interruptions - most of which can be normally handled by people with very minimal levels of training. Now the reader should imagine this machine being entirely automated and operated by programmed schedules. Then, imagine that this machine is fed by the output of a machine placed next to it, and in turn, feeds the subsequent machines down the line with its own output. Any misplacement of paper, paper jam or change in intensity of printing, for example, may compromise the subsequent operation. Now imagine that we are not dealing with paper, but with huge machines assembling 14 major subcomponents of a car and performing complex functions such as multipoint welding, applying anti-corrosion protection, or painting a car with a minute degree of uniformity and precision. A number of machines and robots have to be adjusted to identify and pick individual components in the right position - otherwise they might damage the tools or the part being handled, or the drilling, milling or fixing operation may fall out of place and cause further damage. And all this needs to be performed under very tight production schedules and with very little tolerance for errors. To finish the picture, the reader only needs to imagine the organisational complexity of coordinating a crew of hundreds of operators, maintenance and other technicians, who are supported by systems specialists and the invisible staff in charge of getting the orders, preparing the specifications for each car and supplying the parts so that they arrive on the production line just-in-time.

Here we are more interested in the similarities than in the differences between the two plants. What changes is the degree of integration and, consequently, the more intensive requirements of coordination of physical parts, orders, machines and the human operators. Both plants illustrate two different levels of complexity involved in automated operations - complexity being a function of the level of integration, and the flexibility that ensues. In both plants, the nature of the work performed is very similar - as is the nature of the skills required. But what exactly are these skills?

II. Skill requirements

Both plants described above illustrate the use of technology intensive, highly integrated production techniques. However, not everything is automated - some operations are not automated for practical reasons, others, for economic ones. The data on personnel at both plants confirm that the majority of the workers are not skilled - 1200 in Termoli and 4800 in Casino (39% and 68% of the total labour force, respectively). However, these same data show the relatively high number of skilled workers necessary for automation. This contradicts a general idea that automation and high tech bring in unemployment and make jobs more repetitive or more boring. For most people, the job is essentially the same - in spite of the fact that it is now performed under more comfortable conditions. But the number of technically trained people more than doubled after automation was introduced. The idea that technology is synonymous with push-button jobs was not verified in these plants.

Our central concern is to understand how training needs are determined, how they affect the different workers, and how people are trained to cope with the new requirements.

New training needs arise, to some extent, from the complexity of the new equipment - i.e.- to some extent they can be considered as a technological imperative. For example, robots require more complex maintenance, which include electronics. Operations usually require some knowledge of computer programming. This is true of a small firm operating a CNC machine in a home garage or of a large corporation like FIAT.

But the number of machines, their complexity, the interaction between the machines and systems, the speed of production, among others, also affects the skill required for smooth operations. Moreover, the configuration of machines creates different skills requirements: machines can be designed to be more or less intelligent - more or less automatic - thus changing the balance between the skills required for operations, for control and for maintenance. Here we start to see how it becomes difficult to talk about a technological imperative: are the skills required by the machine or was the machine built in a certain way to respond to a certain level of skills available?

Finally, the skills required also depend on the way the work is divided among workers - which, in turn, depends on the way the plant is managed, the role of the supervisors, the existing skill level of the workforce and the training mechanisms put in place. In short: machines and systems present some operational and maintenance requirements - regardless of the division of work. But this is only a limited part of the skill needs story. The configuration of machines and systems to fit a particular production purpose, as well as the organisation of the workplace and the division of work, determine to a large extent which skills are needed where, and who should be doing what kinds of work. Let us try to analyse the skill requirements from these two different perspectives: the technological imperative and the work configuration.

The perspective of the technological imperative. Conventional tasks analysis methodologies can be as useful for understanding high tech skill needs as they are for production using low-tech. Skill needs are derived from the a static analysis of operations, related maintenance and quality control functions.

Skills required for operations depend essentially on the configuration of the machine. A high tech machine can be totally automatic, including self-diagnosing, error correction, retooling, routine checks and quality control.

Operations are then essentially limited to pushing buttons - and in some cases can be far removed from the actual shop floor, as was thoroughly described by Zuboff (1988). More often, however, high tech machines require human interventions for a number of tasks which might include loading and unloading parts, visual inspection of equipment and products, tooling or retooling the machines, making adjustments directly or through computer programming, taking decisions concerning stop-go or rerouting of production, as well as performing a number of quality controls, analyses and reports. Operations usually involve more than button-pushing - and consequently - require a number of operational, technical and non-technical skills.

Regardless of the level of automation, it must be noted that the nature of the operational task is dramatically changed - when compared with conventional production techniques mostly based on mechanical or electro-mechanical means. There, the operator, using his body, his physical and technical skills intervenes to perform the change in the object being produced. To ensure that work is properly done, workers are supervised on the spot, and the products submitted to a different number of inspection points. Now it is the machine that produces - operation becomes a management task: the operator manages the machine - but it is the machine that performs the work. This requires fewer craft skills and more intellectual, planning and problem-solving skills from operators.

When final products should reach high quality or zero defect levels, it is generally more critical for machines to automatically perform quality control functions than to actually perform the production tasks. Thus, intermediate situations exist in which the production is still highly physical, or only semi-automatic, but the controls are automatic - or even integrated. It is not uncommon to find highly integrated automated plants in which robots live side by side with the human operators working at frenetic rhythms - just like in a Charlie Chaplin movie. Except that now the controls are implacable - there are no margins of tolerance for detecting and exposing errors.

In the case of totally automated production, operators can become far removed from the actual shop floor. Their tasks consist of monitoring the behaviour of machines through computer screens. The difference is that instead of noise, smell, heat and other physical data they have to rely on numbers, symbols, graphs and other highly symbolic materials.

A critical challenge of operating high tech machines - regardless of the degree of physical closeness or remoteness - is to minimise, or eliminate machine down-time. Critical down-time, in its turn, is not determined by the machine alone: it depends on the cost of the equipment, the size of the batch and the number of changes required in the specifications or tools used for production. But it mostly depends on the interaction between the output of this machine and the sequence of events down the line. Operating a machine non-stop requires a number of tasks to be performed - depending on the degree of automation: ensuring correct quantity and quality of parts, ensuring that machines are adequately tooled and regulated, ensuring that performance is according to standards. These functions can be automatised to different extents - and thus require different production-related skills.

Maintenance is another critical requirement. High tech machines require preventive and corrective maintenance. Margins of tolerance, however, tend to be increasingly narrower, thus requiring finer adjustments. The degree of automation of maintenance varies with the specifications of different machines. Some are able to perform routine maintenance tasks; others can carry out self-diagnosis as well as some corrections without human intervention. In most cases, however, the higher the degree of automation, the higher the demand for human intervention.

Preventing down-time - which becomes the critical task on the shop floor - is vitally dependent on appropriate maintenance. Ensuring proper preventive maintenance is not enough: it is now important to prevent problems from occurring. Checks and controls are multiplied - in quantity and complexity. The earlier the

diagnosis, the quicker the intervention. Troubleshooting must also occur in a very short time - and interventions requiring stoppages must be kept to a minimum.

The range of possible problems is also very broad: mechanical, electric, electronic, pneumatic, systems, fluids, controls, defective parts. But this is not news: the news is the interactions. Most automated machines are mechatronics artifacts - they are more than a mere aggregate of mechanics and electronics. The more the circuits are integrated - the more it becomes difficult to locate problems- and to correct them. Special skills are thus required to figure out what the problem is - and how to deal with it. The quicker, the better.

In the medium term, proper maintenance of high tech machines includes figuring out solutions to avoid problems associated with the behaviour of the machines, with those caused by the interaction between machines and parts (geometry problems, for example), and the solutions pertaining to improving the configuration and performance of the system as a whole. Problem finding and problem solving skills become in high demand - and this is part of the explanation behind the explosion of quality circles throughout the world of modern manufacturing.

Finally, an analysis of tasks required on the shop floor has to include quality concerns. As mentioned earlier, many quality controls can be embedded into the machines and performed automatically. Some cannot - or are not. The level of quality is also not determined by the machine - standards of performance are determined by the requirements of the market, the firm, and the cost-efficiency balances to be achieved. The same machine can operate at a level of quality of 60, 80 or 99%, depending on the goals and constraints of production. But quality control requirements would change - and change exponentially. As illustrated elsewhere (Oliveira,1991b), changing quality control requirements from 1/1000 to 1/100,000, to zero defect creates enormous constraints on the skills required of all those involved in production. Throughout the production phase, human interactions might be necessary for monitoring, testing, anticipating and intervening in time to prevent quality problems to arise or to spread.

Concerns with quality are also intimately linked with those of efficiency. In the traditional factory, these concerns are still typically separated - and special units exist to deal with the different priorities. The world of automotive manufacturing still faces these same issues, but cannot deal with them in the same way since the Japanese started manufacturing virtually defect-free cars. Quality still has a cost - but it must be improved every day, in every way possible. It works as a constraint on production, or as an integral part of the production process. Obviously quality cannot be achieved at an exorbitant cost - but lack of quality can cost the firm its own reputation - or survival. While there is a limit within which machines themselves can control themselves and improve quality control, there seem to be no limits to human creativity and imagination in devising new solutions to improve quality.

But here again we can see that quality is not a technological imperative. It is a man-made concept. What automation introduces is the possibility of delivering the promises of virtually defect-free products. But it is up to the organisation to create the conditions that lead to such results. This is why production, maintenance and quality functions tend to merge under the same supervision, and, sometimes, they become the responsibility of the same workers. But this already brings us into the realm of work configuration.

The work configuration perspective. Analysing skill requirements based on the characteristics of the machines themselves would only lead to a very aggregate and static level of needs. And yet, skills identified through these methodologies would be very specific to the way the machine is configurated, its degree of automation, and its role within the production flow. Given its limitations, the technological imperative perspective is neither a good theory nor a good practical guide to understand skill requirements.

Rather, it becomes more fruitful to investigate, in a real situation, the context within which high tech production tools are defined and used, how the work is organised, and how the issue of skills then emerges. In the case of FIAT, automated plants were designed to simultaneously achieve four goals: flexible production, high efficiency; higher quality, and a better and safer work environment. Other goals or constraints might exist - one of the most important of which is to upgrade the skills of the existing workforce. But let us understand first what these four goals mean.

Flexibility is the possibility of producing the same model of car with different specifications - more than 10, 000 theoretical possibilities - or to produce 65 variations of the same engine to meet different client's specifications. But it also means producing smaller batches of components of final products - thus requiring equipment and production lines that can be quickly and easily reconverted. For flexibility to work properly, not only automated equipment is necessary. Just-in-time techniques are essential to guarantee a steady flow of supply. That, in turn, requires complex management and planning techniques, as well as certification of quality of the suppliers (only certified parts reach the conveyor belt, so that no local inspection is necessary). The higher the flexibility desired, the higher the level of integration demanded and, hence, the higher the level of operational complexity and hence, of skills involved.

Efficiency is the result of the smooth operation of production. The critical challenge is to make machines yield maximum output. But output is only partially determined by the machines. It depends on the competence of the users to operate and maintain them properly, as well as to devise new ways to improve productivity. Since a major requisite for efficiency is to keep down-time close to zero, there is a tendency to bring maintenance skills closer to operations.

Quality is a relative concept: it can be defined as conformity to standards. The higher the standards, the higher the quality. To ensure quality, people and automated equipment have to perform work on parts (drilling, welding, enameling, painting, etc.) according to minimum margins of discrepancy from a given norm. Since machines perform the work in automated plants, checking for tolerance (position, distance, pressure, etc.) involves monitoring the performance of the equipment and production tools to yield maximum quality and output. Only so much quality control can be ensured before actual production (quality of inputs, machines, systems, programmes, control mechanisms). To be effective quality concerns cannot be dealt with as a specialised function: it must become a way of working, an integral part of the production culture. Thus, there is a strong incentive for high tech firms to bring quality responsibilities closer to the front line.

A better and safer work environment is the fourth objective to be met by automation at FIAT - and this goal is also shared in many other automation efforts (for similar trends in other sectors, see ILO, 1991). The considerations involved here are far from being motivated purely by humanistic reasons. Accidents not only hurt people, cause absenteeism and increase health bills - they also disturb production and machines. A badly designed part, or an erratic hand of a robot, can damage a very expensive piece of equipment. Some equipment must be kept under certain temperatures - and some people can benefit from a climatised environment. Preventing all kinds of accidents with machines and people becomes a priority. Improving equipment design, the geometry of part, the quality of tools, the ergonomics of the workplace, are but a few examples of the new constraints associated with the adoption of high tech production tools.

Thus, skill requirements are only partly defined by machines. Technology, and the form it takes in the workplace, is essentially a social construct - as it responds to a number of man-made definitions concerning the interactions of man, machines and systems. These definitions are guided by the production goals, the objectives of introducing technologies as well as - but not primarily - by the technical characteristics of

the equipment. These definitions reflect the way work is organised, divided, remunerated, and the way individuals are allocated to the different jobs.

New occupational roles: skill requirements. It is hard to imagine a flexible production plant with rigid organisational patterns. In fact, some authors argue (Hoffman, 1989) that many firms in the U.S.A., for example, use more automated equipment than their counterparts in Japan, but fail to obtain increased productivity because of inadequate organisational arrangements.

FIAT introduced major changes in the organisation of the workplace as a result of automation. Such changes are not only reflected in the definition of jobs and tasks analysed below, but also in the distribution of power and authority and in the change in the communication patterns among staff of different hierarchic levels. Overall, the organisation became flatter, some jobs became more important, and the goals of flexibility, efficiency, quality and safety became equally legitimate and were brought in under the responsibility of the same manager - thus minimising opportunities for conflict and maximising the chances for collaboration of the staff with different perspectives on these issues. The new division of work and the new job definitions affected most of the jobs, but here we concentrate on three of the jobs most affected by automation, those of operators, maintenance crew members and line technicians, all illustrated in Figure 4.

Operators. The critical task of operators is to manage machines to operate non-stop. A more important task is to monitor the machines and the controls associated with them. Monitoring may involve making sense out of symbols shown on the computer screen or actually wandering around the shopfloor to detect any different behavioural pattern in the production tools or the products themselves, like noise, smell, colour, appearance or shape. Routine testing and filling out reports are also part of most operators' jobs. Differently from the past, where they were in charge of one machine, operators are now responsible for a sub-set of the production functions, which may include one entire production line or parts of it. Physical mobility has become both possible and necessary - and has brought with it additional degrees of freedom and responsibility.

Operators in most production lines are also expected to be involved in maintenance functions. At the simplest level, they are expected to anticipate problems - and to try to avoid them. If problems occur, they are expected to diagnose them, and either to take action - if they can correct it themselves - or to call the appropriate maintenance specialist. Note that traditional hierarchies no longer hold - the operator first calls the maintenance - and only later might he inform his supervisor. Operators in some production lines have the authority to stop the production line, to re-route production to other lines or to re-programme it to produce a different product if the problem is associated with the supply of parts. In a sense, they enjoy a wide margin of responsibility and authority.

"Before I was a hand. Now I am brains". This dramatic statement by one of our interviewees nicely synthesises the radical change in the knowledge and the skills required of these new operators. Operators now need to use their brains in a number of ways: to perform tests; to sense problems; to diagnose problems; to intervene; to take decisions about whom to call; to give their opinion; to contribute suggestions to improve operations.

This same operator said: "Before, I would sweat my shirt here and go home to rest. I never thought about the production line. Now, I cannot stop thinking. Even when I am resting at home, I keep thinking about ways to improve performance, about how to avoid some problems, about how to improve the efficiency of my machines".

The range of knowledge and skills necessary to perform these functions is quite large. First, it involves technical knowledge. For operators, knowledge requirements are usually limited to the functioning of the machines, and the logic of their operations. Often, however, operators

Figure 4

	Operators	Maintenance crew	Line technicians
Educational Background	OLD: 6-8 years + experience NEW: 8 + Voc. Training	8+3 (Vocational training)	11+3 (technical training)
Critical Challenge	Manage machines to operate non-stop	Timely and prompt interventions without disrupting operations	Coordinate and lead technological team
Typical Tasks	- Monitor - Diagnose - Intervene - Decide (stop/go) - Contribute to improve quality and efficiency	- Preventive and corrective Maintenance	- Coordinate technological support for a given production line - Lead the technological team
Critical knowledge & Skills	- knowledge to operate 1 + machines - basic concepts(Sc. & Technology) - machine/tool specific information - monitoring with computers	- Know specialisation (mech, electr.) - Know machines thoroughly - Plan & schedule interventions to minimise interruptions - Coach operators - Group problem solving - Communication skills	- Technical knowledge of the various specialisations - Technical knowledge of machines & systems - Leadership/problem solving/and communication skills
Characteristics of formal training provided	- 5-12 months - applied, machine centred technical knowledge + practice - General info/skills: - communication - problem solving - using computers - quality control	- 6-8 months, before installations - Upgrade specialised technical knowledge - Machine-specific knowledge at suppliers site - Retraining only when new machines are introduced	- 6-7 months training - new organisation, systems/new techniques(CAD/CAM, etc.) - Management and problem solving skills - Technical upgrading, if needed in some areas - Upgrading through short technical seminars on specific issues(quality control, etc.)

are expected to understand at least the logic of the entire production island or the production sub-system, and the inter-relationship between its various parts. The more knowledge one has - the more one becomes flexible and able to operate other components. Technical knowledge includes operational information (how to operate the machine) and specific skills (how to read signs on the computer; how to fill out a certain control form; how to interpret an index or a parameter). It may also include general principles of automation, of electronics, of mechanics, etc., according to the specific characteristics of a machine or production line.

Non-technical information is also required in a number of areas. First, operators must be able to read and write. They need to read instructions, tables, information, technical manuals. They need to fill out forms, tables, graphs and give suggestions for improvement. They also need to communicate verbally - and efficiently. They need to explain clearly what a problem is, and what they think the cause or the solution is. Problem-solving skills are thus highly valued, and individuals are expected to use logical thinking to identify and analyse the technical problems of the machines under their responsibility. They need to intervene in their quality control circles. On these occasions, they are not talking to their peers, or their supervisors: they will be talking to people of higher ranking and with higher technical backgrounds - and yet the operators are expected to present and defend their own views. This is vital for the organisation to be able to learn from those closer to where the problems are. As a consequence, they are expected to work collaboratively in groups, in the search for commonly defined production and quality goals.

An intriguing characteristic of the skills illustrated in the last paragraph is the simultaneous level of generality and specificity. All the skills enumerated above are generic - they are the skills that schools are expected to teach people: to read, write, think, communicate. Yet, for the most part, they are very much applied to specific contexts. In many cases these skills were not properly taught at school - thus increasing the need for in-firm training. This is perhaps a characteristic of the transitional stage in which high tech firms find themselves - when most of the workforce, at least at this level - has not benefitted from a good educational background. It might be possible that with the rising levels of education and pre-employment training of the incoming workforce the need for developing such basic skills will decrease, and production workers will not be so puzzled about being brains, and not hands. For the time being, however, this is a major revolution in skill requirements, skill deployment and skill use.

Maintenance crew. As illustrated in Figure 4, maintenance crews are also expected to work differently from those in conventional production plants. For one thing, the automated machines are more complex. Even specialised mechanics or electricians need to know a little more about these inter-relationships. Given the high price of the equipment, time for maintenance becomes highly priced: more has to be done in less time. Planning, diagnosing and intervening have do be done more quickly. Avoiding problems and carrying out preventive maintenance become prime targets - and for that the collaboration of the operators is essential. The more they know, the better. In fact, the division between operation and maintenance becomes tenuous - and the major task of operators becomes a traditional function of maintenance in order to keep machines running. Training and coaching operators thus become a routine task for maintenance crew members and replaces the traditional structural rivalries between these groups commonly encountered in conventional plants (Crosier, 1964). Figure 5 illustrates the organisational chart at the Casino plant, where one sees the functions of production engineering and operations under the same manager.

Figure 5

Organisational chart, Casino

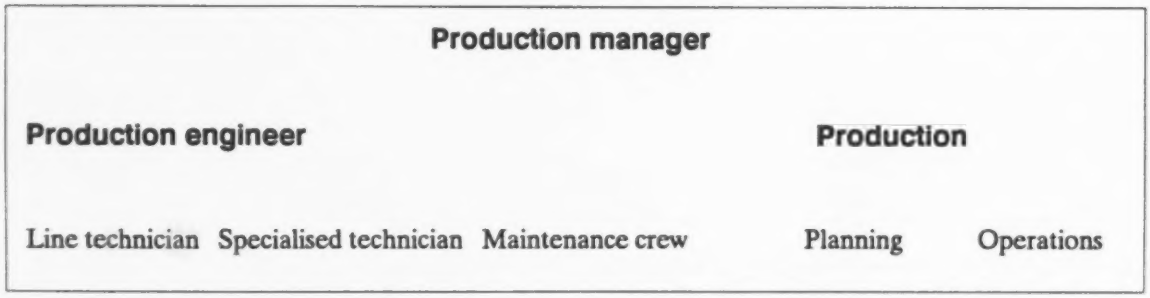


Figure 5 also shows a functional separation between a generalist maintenance crew and specialised technicians - even though they are expected to work as a team, and for that reason they are under the same supervision. The difference between these three groups is one of function and degree of specialisation. Maintenance crew members tend to be more specialised in certain areas, and are supposed to perform first and second level maintenance activities related to specific equipment or production lines. Specialised technicians have in-depth knowledge of their respective areas, and only intervene on special occasions.

It is expected that maintenance workers will increasingly become multi-skilled or polyvalent. This means the ability to work across machines and production lines, but also to work across specialties. In practice, so far, there has been very little training of multi-skilled workers. From a practical point of view, the obvious advantages of a multi-skilled worker able to deal with any type of problem had to be weighed against the lack of in-depth knowledge about the functioning of specific equipment and production lines - such knowledge being a most valuable asset in the short run. In other words, there is a structural conflict which is resolved by sequential attention to the different priorities. One time the short term needs of the production line take precedence - another year the individual and the long term interests of the firm prevail.

A third type of specialist whose functions are listed in the third column of Figure 4 is the line technician, a creature of high tech, and whose functions are discussed next.

The line technician. The line technician is FIAT's name for a new occupation in the making. It is a blend between the multi-skilled, polyvalent worker, and a specialist in a given production line. In other words, he incorporates the best of both worlds. He knows, in sufficient depth, about the various technical complexities of the equipment and the tools used in a certain production line. And he is responsible for deploying all the technical resources to ensure smooth operations of these machines.

The skills required of a line technician are those of an integrator. As a technological integrator, he himself has to be able to integrate the technical knowledge necessary to understand the functioning of a certain number of machines. As a leader without line responsibilities (Figure 5), he needs all the human and social skills he can develop to integrate the contribution of people at the various levels of the organisation to ensure the smooth operation of the technological support system.

The line technician symbolises an interesting emerging trend in the world of high-tech. According to his job design, his authority derives simultaneously from his technical and his

human competences. His level of technical competence must be very high - even though different from that required of a typical maintenance specialist. While the latter needs to be more specialised in this field, the former needs to know the basic concepts of each specialisation, but must be able to integrate these concepts in very practical ways to figure out what to do. However, this multi-skilled technician enjoys no formal authority - and in fact he needs to work through supervisors and other organisational lines - to coordinate the technology team, i.e., an invisible college formed by all those who can contribute to maintain operations and improve flexibility and quality. Leadership, communication, group problem solving are only a few of the non-technical skills required to develop such a new breed of high tech workers.

Two important groups of workers were left out of Figure 4: the non-skilled workers and the supervisors. Yet, technologies affect their working lives in many important ways.

Supervisors are not a species in extinction - but they are probably on the brink of a significant mutation. First, high tech firms increasingly adopt bottom-heavy structures, with very few hierarchic layers. In Japan, factories typically have only three levels of hierarchy; in Europe, the typical factory has nine layers, but at FIAT it has already been reduced to six, and will tend to be reduced even further. Second, as illustrated by the emergence of new occupational profiles such as the operator, the multi-skilled worker, or the line technician, the nature of supervisory jobs is dramatically changed. Supervisors are no longer able to know more than supervisees. Their formal position no longer carries the authority it used to. Employees are more flexible, but also more competent and more critical, hence less disposable. The ambiguity of their present job reflects the ambiguity of defining production. Before, supervisors supervised people who were in charge of production. Now, people supervise machines - it is the machines that produce - and supervisors might have to look into other activities further removed from the production line, unless, of course, they may be able to provide technical support - which is increasingly more difficult.

At the present stage of industrial transition, a supervisor at a FIAT automated production line may oversee 8 to 10 operators who know their work better than he does, who have skills and machine-specific information not so easy to replace. Operators now talk directly to maintenance crews and participate in decisions concerning production. Sometimes, urgent problems require operators to obtain direct assistance from other staff, from suppliers, or even from friends working at a competitor's plant. As an operator put it the supervisor (now) is a friend. We still need him a lot, particularly to coordinate the work with other groups and decide on product change. But, as it is today, we know that we cannot rely on him for technical advice. The critical task of the supervisor, in this environment, is to ensure the achievement of production targets at desired levels of quality and efficiency. He is likely to spend more time in planning and coordination functions - and thus become increasingly far removed from actual operations.

High tech certainly creates new ambiguities for the role of supervisor. Such ambiguities reflect a mandate which combines some features of the workplace of the future (quality, productivity, open communication) with the means and the image of the supervisor of the past. Whether or not layers of supervisory positions will tend to disappear remains to be seen in the future. At the present stage, and differently from the other three groups of occupations analysed before, it becomes very difficult to detect any noticeable impact on skills and training for supervisors. A sign of the changing times?

At the other extreme, firms like FIAT still employ substantial numbers of unskilled workers, engaged in conventional production or in complementary activities, such as finishing jobs, upholstery, loading and unloading tasks, packaging, cleaning, etc. At least in the case of FIAT de-skilling did not result from new work technologies, because unskilled workers

remained in the same jobs - or took similar unskilled jobs in the new production lines.

Nonetheless, a few changes in knowledge and skill requisites are noticeable. First, the channels of mobility from unskilled, to skilled, to technical or supervisory jobs are virtually extinguished. Mobility is only possible now through knowledge - theoretical and technical - for which practical experience can only contribute in a complementary way. For those willing to make a career, this is no longer the way to start. This also means that an increasing cleavage is being formed between the nature of the work of those involved in high tech production, and of those in conventional production, or in non-technical positions. Second, unskilled, semi-skilled and manual workers are being required to use basic skills such as reading, writing and understanding instructions, to respond to new demands of flexibility or quality. For example, operators of fixed-automated machines now need to read the specifications of the products, perform some quality control functions and participate in quality circles - functions which require basic numeracy, literacy and communication skills - besides having a basic understanding of quality issues.

As discussed above, the way new work technologies were deployed created massive requirements for upgrading skills which affected three categories of workers in particular: the operators, the maintenance specialists and the line technicians. But we have also seen that other groups were affected, including the semi-skilled workers. For those, a higher level of basic skills is required not only to improve the performance of their present functions, but also to have a hope of promotion. Having analysed the origins of the skill requirements and the nature of the skills required by the work arrangements put in place, we now turn our attention to the training activities which were developed to respond to such skill gaps.

Coping with skill requirements: training and retraining the workforce. The training efforts of corporations introducing high tech production are amazingly high. While the average industry in the U.S. and most European countries invests from one to two percent of the payroll on training, high tech industries invest in average five to six percent, and some ten percent and more. This is the mirror image of the skill requirements presented in the previous section. Figure 6, below, gives an account of the training efforts at the Termoli plant between 1984 and 1989.

Table 6
Training at Termoli

	1984	1985	1986	1987	1988	1989
Trainees	483	351	239	610	762	646
Hours	257,690	247.351	113,151	236,640	165,196	88,785
H/T	533	704	473	387	216	137
Man/Days	32,211	30,918	14,143	29,580	20,649	11,098
Costs*	8.5	5.7	5.9	3.4	5.7	3.4

* in US$ million

Data from the Casino plant reveal similar efforts: over 200,000 hours in 1987/88, slightly less in 1989, 139,072 hours budgeted for 1990 and 122,000 for 1991. In 1990 training involved mostly technical and supervisory personnel. Over 6,000 man/days are budgeted for 1991 for training on quality issues alone. Even though it is expected that the intensity and duration of formal technical training will decrease over time, as is already visible in the case of Termoli (H/T), training should remain as an important activity, and it is expected to represent at least three to five percent of annual operating costs.

Are these training investments high or low? In absolute terms, they seem to be fairly high. For instance, at Termoli, initial training represented about five percent of the total investment costs in the new automated plant. Recurrent costs vary from three to five percent, depending on the plant and the phase of implementation of automation. Training costs are also not easy to interpret: sometimes they include direct costs, sometimes they include opportunity costs. Some types of training are not directly costed - as when training is part of the contract with suppliers of a new equipment. Overall, however, training is becoming an increasingly heavy factor in the overall costs of production.

The dilemma is not between training or no training. Whatever the methods used to calculate costs, expenditures are already perceived as very high, and cannot go up by very much. Training costs are reflected in the final price of the product and directly affect the competitiveness of the firm. The question then becomes: what is the cost of not training?

Lack of training can indeed lead to very costly consequences, and this is currently subsumed under the concept of training deficit. Bastos do Valle (1989, p. 208) illustrates this concept using a study done by VW in one of its plants in Europe, in the early days of their automation. The study quoted by him was done in connection with the launching of a new car model in a partially automated plant. According to the study, no adequate training programmes were provided prior to introducing automation. The costs of specific problems which arose during the production (number of rejects, costs of machine down time, costs of work paralysation caused by lengthier than expected maintenance) as well as the claims brought up by clients with respect to specific defects were computed. The total costs attributed to lack of training (training deficit) amounted to 109 million DM per year. It is difficult to evaluate whether these costs (which are real) can be directly attributed to lack of training alone - or to the lack of other variables in the implementation process. The fact is these costs were dramatically reduced in the next round, when careful training was offered before implementation took place.

The distribution of training: who gets how much, and when. According to most of the senior staff of FIAT interviewed, there can never be enough training: the more, the better. However, training is not a free good. Cost considerations force the organisation to keep training to a minimum, and focussed on specific priority topics and priority target groups. Timing of training is also a crucial variable.

At both plants, training took place on a timely basis, well before the new operations actually began. Maintenance crews were trained first, for periods varying from 8 to 20 months. A substantial part of training consisted of monitoring the production of automated equipment at the suppliers' firms, and overseeing and participating in their installation at the new, automated plants. According to some of the trainees, this has been the most important part of their training. But a significant part of this training consisted of formal courses.

Operators took formal courses, for periods varying from 5 to 8 months, depending on the previous level of technical or vocational training as well as the experience of each individual (Figure 7). Each module took 35 days to complete, and supervised practice immediately after theory took 10 days. More than two thirds of the training was theoretical - a major departure from traditional training of operators, and a sign of the new technology era. Learning from experience was no longer enough. Be-

sides, operators had no previous experience with automation to build upon.

Figure 7
Training programme for operators

Module I	Module II	Module III	Module IV
Pneumatics Maintenance Supervised practice	Electromechanics PLC Diagnosing skills Supervised practice	Machine specific Instrumentation Numeric control Supervised practice	Robotics Sup. practice

Actual operations started under the responsibility of the maintenance crew. The new operators were progressively introduced by them into the mysteries of the functioning of the new machines, until they became fully operational.

The training of specialised technicians was also quite varied and diversified, according to the background, specialisation and nature of the future work of the trainees. Most of it occurred after the new plants were in operation. However, some specialised programming tasks at the Casino plant required as much as 18 months of full-time training before the implementation of the new system.

Finally, as reorganisation and quality control plans were introduced, training in management, costs, quality control and similar issues was progressively introduced to a broader audience, including office workers and supervisors. The purpose of these training activities was to disseminate a common vocabulary and an understanding of the nature of new production technologies and to create an organisational culture around the issue of quality.

After these massive, intensive training efforts were put in place, most of the additional learning necessary was limited to specialised courses of variable duration - for example, when a new machine or a new system is introduced, or for the purposes of increasing the flexibility of one individual or a production line.

However, as FIAT is observing in its daily operations, learning is becoming a way of life, a way of producing. Individuals learn everyday. The corporation not only wants them to learn to produce better. It also needs to benefit from their learning and their ideas to improve the efficiency of its practices. How this type of informal learning occurs is the theme of the next section.

III. Informal learning

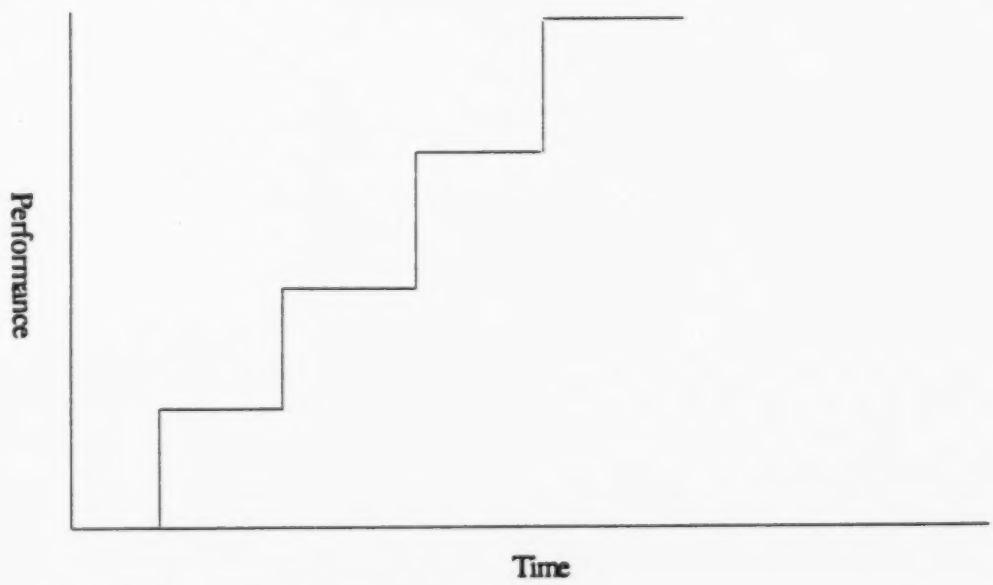
Automation technologies require workers with higher levels of education and training. The range of basic skills becomes larger. The conceptual basis necessary to understand and adapt to new systems and machines becomes broader. The idea of trainability itself - i.e., the ability to be trained - supposes a broad intellectual basis which is best acquired under a formal education environment.

But there are clear limits to what can be provided by education and training systems. Even on-the-job and in-service formal training is limited by time available, as well as by institutional, financial and human resources. More money spent on training affects the final costs - and hence, competition and long-run survival of individual firms. Moreover, formal training is only part of what is required: there is a great amount of learning that can only occur on the job. Learning on the job is a requirement of the shape of the learning curve of high tech firms. Whether or not organisations are able to learn and the extent to which they can is directly related to the organisational format and the incentives put in place for people to interact. Fortunately, high tech firms have discovered ways to increase learning without formal training. This section explores why and how modern manufacturing firms are becoming more learning-intensive than technology-intensive organisations.

The concept of the learning curve is not new (Figure 8). The curve-shaped line illustrates the learning curve of conventional manufacturing firms.

Figure 8

Technology and conventional production learning curve



Learning tends to be very fast in the beginning, and reaches an asymptote or a plateau relatively quickly. Learning is typically concentrated on a few individuals - methods engineers, supervisors, specialised consultants and work analysts. Once the uncertainties of production are mastered, they are transferred to the people down the line, through training, instructions or rules to be followed. In general, operators, skilled and unskilled workers are not supposed to think - this is a specialised job in the firm. A few people think; most people do. These techniques which prevail in conventional manufacturing were primarily conceived for the production of large batch runs, or for continuous flow operations. At the same time, the firms operated under relatively easy competitive constraints, and quality was not a primary concern of producers or clients. For many years the model worked - and in fact was exported to other production arenas where it did not prove to be so efficient. The limitations of these strategies become obvious when these same firms launched ad-hoc productivity or quality campaigns. Not accustomed to thinking, employees react, shy away, or simply do not engage in these processes. It is true that in many cases the firms themselves are only paying lip service to quality and other concerns which happen to be fashionable. The difficulties of firms operating under these organisational constraints to set up quality improvement circles are very understandable: it represents a major break from standard practices, and is often inconsistent with routine operations. We will turn to this topic later on.

The learning curve of the high tech firm is represented by the steps. Learning starts very low - there are many uncertainties associated with production: a new product, a new production line, new machines and tools, new operators, many new variables at once - including the many new changes of tools, parts or specifications introduced during the production process. Learning necessary to improve the yield of a new production line becomes a process of group discovery. The knowledge to do it is not yet available, and it is no longer a question of controlling a few variables or learning to tune-up or calibrate the new production tools. Uncertainty is not ignorance or lack of experience, but more often reflects the complexity of the problems, the difficulties of detecting the cause of inconsistent error patterns and the limitations imposed by the state of art. Technological knowledge is created on the go, by the firm's capacity to understand its own problems and cope with them, as well as on the basis of the existing, but evolving knowledge coming from the outside world. Very often, initial production yields are very low - production based in highly integrated circuits can start with initial yields as low as 40 or 50%, and take a few months of production to reach 70 to 80% of defect-free parts in the first round. In such cases, learning starts from a very low level, and progresses by steps. But it occurs at real time; no one in the firm has the opportunity or the time to learn first and then teach the operators later: all learn at the same time and from each other, and they incorporate learning into the process of doing. Doing and learning become closer together. Whether this is a long-term phenomenon associated with the evolving stage of electronics or whether it represents only a short-term stage which will be eventually mastered and transformed into the traditional learning curve is not known. For the time being, however, it seems to be characteristic of high tech industries in general - and thus requires specific coping strategies. Some examples might better reinforce the argument.

Figure 9 illustrates two different learning patterns. Firm A is an auto manufacturer in Europe and Firm B, in Japan. Both produce the same number of cars.

Figure 9
Fighting down-time

	Daily production	Robots	Maintenance crew	Down-time
Firm A	850	100	250 +	1.5%
Firm B	850	350	30	0.2%

Source: Bastos do Vale, op.cit. p. 182

Even though technological complexity is greater at the Japanese firm B (350 robots), maintenance crews and down-time are very much different. The difference in production costs - and quality - are directly reflected in the market position of these two firms. The superiority of Firm B is not in the number of robots, but in the superior ability of its personnel to deal with maintenance problems.

The way firms deal with quality improvement and suggestion boxes further illustrates the point. Figure 10, below, gives an account of the learning curve at the Toyota Motor Corporation.

In 1960, suggestions were very low, about 9,000 per year. But the capacity of Toyota to understand, analyse and implement the suggestions were also very low - only 39%. As Toyota entered into the high tech world, in the early 70s, the number of suggestions increased while the capacity of the organisation to learn from these suggestions slowly adjusted, until it reached a very high level - but not quite a plateau.

Figure 10
Implementation of suggestions by employees at Toyota Motor Corporation

	Number %	Implemented	Suggestion per employee
1960	9,000	39	1.0
1970	40,000	70	2.5
1973	247,000	76	12.5
1976	380,000	83	15.3
1979	575,861	91	13.3
1980	858,039	94	19.2
1981	1,412,565	95	38.8
1983	1,655,858	96	31.8

Source: Kaplinsky, 1988, p.461.

Figure 10 also illustrates a mutually reinforcing mechanism: individuals tend to contribute more suggestions to the extent that the organisation is able to incorporate these suggestions into practice. The figure implicitly suggests that individuals will not contribute if the firm is unable to implement their ideas. It we assume that in order to make feasible suggestions individuals have to think and learn, the number of suggestions implemented can be used as a proxy of organisational learning.

For the sake of comparison, at its present stage the two FIAT plants mentioned here have been able to incorporate about 20% of the suggestions received from workers. These relatively low figures indicate that it takes time for organisations to learn to incorporate such suggestions. In other words, to learn how to learn. It requires preparing the workforce to improve the quality of the suggestions, which would then become more feasible. It also involves the deployment of adequate incentive systems and other organisational features which take time to evolve and to put in place. In the case of FIAT, the adoption rate is only an estimate - no careful statistics have been kept. This estimate is only related to the written suggestions - and not to a number of other mechanisms the firm puts in place to improve quality and efficiency, such as quality circles, quality projects, etc. Nonetheless, there is a clear awareness that much remains to be learned by the corporation on how to stimulate more and better suggestions, how to increase the rate of implementation of improvements and on how to design the organisational mechanisms and incentives to increase both these rates.

Another example of informal learning can be observed in the practice of job rotation. As previously shown in Figure 2, the number of engineers (all of them counted as managers) at both plants is remarkably low for a high tech operation. In part it reflects market imperfections in the supply of engineers in Italy: both plants visited would like to hire more engineers, if they were available. Moreover, the training of engineers in Italy seems to be rather theoretical, and not necessarily geared towards high-tech industries. One of the strategies used by FIAT - and common in other countries like Japan and Singapore - is to engage young engineers in operational and technical activities during their first 2 years in the firm. Not only do engineers learn operational and practical skills, but they also learn to communicate with technicians, to participate on an equal footing in the invisible college (technological team) and thus create informal but permanent links and channels necessary to raise the technological level of the dialogue at the shop floor. Learning, doing and teaching thus become inseparable activities, and they build upon each other. This is perhaps the most important mechanism for the firm to learn how to learn.

The physical location of engineers, technicians and supervisors is another important component of the structuring of this hidden world of informal learning. Offices have no walls, and are located in strategic points around production lines. The few office-holders seldom stay in their offices for more than 20% of their time. Managing by wandering around is the norm, since their physical presence is constantly required to coordinate work, to intervene, or to give technical contributions to the permanent process of anticipating, solving problems and designing solutions.

Motivating and sustaining such behavior in the long run requires adequate organisational design. A quality improvement campaign can only be sustained in the short run; individual suggestions can be increased only by reward mechanisms. But a permanent attitude towards thinking, learning and sharing learning experiences can only be sustained with proper organisational formats (for more evidence concerning the empirical validation of this thesis in the engineering industry in general, see Hoffman, 1989). Such organisational design variables are reflected in the recruitment and training practices, the job description, the reward system, and mostly the overall organisational and supervisory climate.

Recruitment practices have already been analysed: there is a clear trend to hire people with more schooling, i.e., those more able to learn, and to be trained. Massive training ef-

forts - and the heavy investment in conceptual and technical, rather than skill training - also reinforce the increasing importance of learning.

Job descriptions are another important design variable. Jobs of operators and maintenance people, for example, are described in such a broad way as to create a permanent imbalance that motivates individuals to keep learning. The job descriptions are presented as sort of incomplete jobs, for which no amount of knowledge and skills is enough: there is always something else to learn to become a fully-fledged operator. An operator can always learn more about other machines, about the functioning of the entire system, about maintenance, or about other technical specialities. The same is true of the maintenance specialist, and so on. The label technician has no meaning in such an organisation, since all production workers are involved in technical activities. What varies is the amount of technical competence one can offer, not the technical nature of the jobs to be done. For example, engineers are expected to get their hands dirty, while operators are supposed to formulate their suggestions in writing and present them at a formal meeting. This is a major departure from very specific definitions of tasks and jobs typical of the organisational practices of conventional manufacturing firms.

What happens in the daily activities of the people, however, is what really matters. Individuals will be likely to respond if the organisational climate and supervisory practices motivate and reinforce activities which involve learning, making suggestions, or trying out solutions. The problems raised by the technologies only become opportunities for learning if the organisational climate creates room for all individuals involved in production to be part of the solution. In such a work environment, where everybody's opinion counts and is taken seriously, intellectual calisthenics become routine. Relationships between production, maintenance and quality control are thus critical to signal whether individuals should think or should do, whether they should be cautious or aggressive, whether they should contribute or restrain.

But people also respond to incentives, such as remuneration, formal training and career opportunities. Like some other high tech firms, FIAT has no special financial incentives associated with quality and productivity programmes. There are no financial, individual or group incentive mechanisms. Remuneration policies are fairly inelastic, and thus individual salaries are more affected by career opportunities than by individual performance. Thus, most of the incentive systems rely on cultural norms and expectations such as the ones described in the previous paragraphs or in the training and career opportunities analysed below.

Career opportunities may function as a good signal for further training - and learning. Even promotion to operators' jobs - not to speak of supervisory jobs - are now clearly attached to educational background and not merely to years of experience. This acts as a powerful sign for individuals seeking promotion. Operators can expand and enrich their jobs laterally - by learning about other machines, the entire production line, or the logic of the entire operation. Or they can acquire techniques to perform quality control. Or they can incorporate abilities related to maintenance. This is the normal way to create more interesting jobs, and eventually to become a candidate for maintenance or supervisory functions. The same is true of maintenance crews and specialised technicians, who are expected to deepen and broaden their areas of competence - and eventually to become line technicians. But since all these skills are highly complex and can no longer be learned except through practice, formal education and training become thus highly valued - and a premium for those workers starting at the lower ranks.

As knowledge of a conceptual kind is more valued, the opportunities to acquire that knowledge become critical. Loyalty, manipulative skills, and time on the job no longer suffice. Learning and ability to contribute are more valued. Rationing training thus becomes one of the most powerful sources of authority in the

modern, high tech corporation, since it affects not only the quality of the job, but the chances of promotion. And individuals will always find themselves at a crossroads where their abilities and motivations collide or merge with the immediate interests and budgets of their supervisors, the medium-term plans of the plant manager and the long-term interests of the corporation as a whole. The optimum level of organisational learning derives from the resolution of this organisational design equation.

A. An emerging learning-intensive organisation

Flexible manufacturing systems introduce the possibility that firms producing and marketing automobiles today will be producing entirely different products tomorrow. Markets are becoming increasingly volatile. The business of most corporations is being redefined. Corporations enter and leave businesses much quicker than they did in the past. They can change their existing equipment and technologies fairly rapidly. Within such turmoil, the human technology, i.e. the existing capacity of dealing with new knowledge, becomes the most valuable permanent asset of the modern corporation. But the value of this new form of capital is not what the firm knows today, but what it is capable of learning tomorrow - and preferably before its competitors. Are we assisting in the emergence of learning-intensive organisations?

Corporations are indeed finding themselves in the business of learning - they are becoming learning organisations. As a consequence, reorganising the firm to make it more able to learn becomes a primary task of high tech firms. Here we are not talking about the increasing demand that modern corporations put on the educational system - which are reflected, for example, in the U.S. educational reforms started with the launching of the Sputnik in 1957. Nor are we talking about the learning business documented by Eurich (1985), and according to whom corporations would be spending more money on training than the U.S. society would be spending on education. This is only the tip of the iceberg.

The business itself is becoming a business of learning. Human resource development policies go much beyond formal training. Organisational structures, career systems, reward and incentive mechanisms, communication lines and supervision styles reflect the technological culture of the modern high tech enterprise and condition its chances of success. As the authority based on hierarchies diminishes and that based on knowledge increases, the sources of power and authority move to those managing decisions concerning career structures and training opportunities.

As the firm becomes a learning organisation, it improves its proficiency as a manager of learning. Creating learning opportunities goes much beyond formal training, and cannot be left to chance. Managing learning and training is no longer a separate, specialised function of the personnel department: it becomes the key function of CEOs, managers and supervisors.

The FIAT plants studied in this case illustrate, albeit in incipient ways, some organisation design features which facilitate learning. Before concluding, we briefly highlight the organisational correlates and changes associated with four of these new modes of learning, namely learning by being told, learning by doing, learning by visiting, and learning by reflective practice.

Learning by being told - a synonym for training - reaches crucial importance in this process of organisational learning. It was previously illustrated by the massive organised training efforts deployed by FIAT in connection with the modernisation of its plants. But it is not only a matter of providing more training - but thinking about training in different ways. It was probably not a coincidence that FIAT decided to revise its institutional training framework and launch ISVOR before it entered into the world of high tech. This Institute provides unique, high-quality, tailor-made, timely training support that no other organisation in Italy

could probably offer to meet the various needs of the different plants. It also provides extra advantages and flexibility, given the economies of scale which would be impossible to reach at any individual plant. Moreover, by having unique access to the plants, ISVOR can accumulate experience in detecting needs and improving the efficiency of training supply. The use of advanced training technologies such as computer-based training and interactive video-disks is also another mechanism to achieve cost-effective training, while exposing participants to computers and other high tech training support devices similar to the tools found in their work stations: learning technologies becomes contemporary with work technologies. Given its mandate to operate on a market basis, ISVOR must also provide cost-effective training, thus contributing to the the overall efficiency of the entire operation (Oliveira, 1991a).

The extent to which high tech firms can rely on internally vs. externally supplied training cannot be determined beforehand. It depends on a number of factors which vary according to the educational, training and industrial practices of each country and economic sector. The present case - and the strategies adopted by FIAT - suggest that technological changes require a revision in the relationships between general and technical education and in industry training. These relationships become simultaneously more interdependent, but also more differentiated. Let us take a closer look.

As discussed before, the expectations of high tech corporations vis-à-vis the educational system are substantial: they want schools to do what they have always expected them to do (Castro and Oliveira, 1991). No curriculum revolution seems to be required to meet the demands of high-tech firms. There is no need for teachers to become knowledgeable about computers or robots. But now teachers and schools are expected to improve the ability of the average student in basic skills, such as literacy, communication and numeracy skills, among others. It is also expected that students will improve their conceptual understanding of basic scientific reasoning. But this is practically all that seems to be required - yet it is not a trivial challenge for most educational systems, both in NICs and in developed countries.

This general upgrading of the knowledge basis of the population is not a unique requirement of FIAT: it is as important for its suppliers as it is important for its customers, and for individuals in society at large. As Porter (1990) observed, only societies with highly sophisticated consumers can build enough pressure for product and quality improvement. In other words, high tech corporations cannot seriously engage in the learning business if they are islands of competence in the middle of an illiterate society. Economic development supported by high tech production techniques in developed countries and a few NICs is highly correlated to widespread high levels of quality schooling. According to some observers (Castro, 1991) the recent pattern of high tech growth does not seem to show any exception to this rule.

But high tech firms and technologically advanced societies also seem to need a limited, but crucially important contingent of highly qualified people with solid technical backgrounds. FIAT - as most technologically advanced firms - does not hire graduates from academic schools for high tech production jobs: it hires youngsters from technical and vocational schools. What does a high tech corporation expect from such schools?

This question has never been satisfactorily answered in any country - and the behaviour of firms dealing with new work technologies does not seem to make the response any easier. For economic reasons, firms, in general, would prefer schools to prepare individuals for both the short and the long term. They would prefer to hire individuals able to work today, but ready to learn tomorrow. Short- and long-term expectations about the short and long run may vary according to the complexity and the size of the firm. In the case of a large organisation like FIAT - where actual machinery and work technologies are likely to change at increasingly higher speeds - a sound basic technical background seems preferable to specific, narrow

job-oriented training. For example, it would be more valuable to teach people the logic of programming than to teach a specific computer language. It would make more practical sense to teach the logic of flexible manufacturing systems than the operations of a specific production line. In the majority of developed countries and NICs, technical schools and polytechnics are only starting to scratch the surface of this problem. Suffice it to observe how their curricula have been changing in the last 15 years.

The segmentation of the education sector and of the labour markets created an intermediate layer of trained people. These are the skilled workers - still in relatively great demand by conventional and high tech firms - but probably the group to be most affected by technological change. In the past, skills - or vocational training - emphasised physical manipulation and craft, rather than intellectual, skills. The operator in the modern corporation needs a balance of both - but a balance which is increasingly shifting towards the conceptual side. Assuming a normal distribution of capacities and aspirations in society at large, teaching correct work attitudes and habits through practice, coupled with a minimum conceptual basis, would seem to be the ideal curriculum for vocational schools, from the point of view of modern high tech corporations. It is at least curious to observe that countries such as Germany and Switzerland, with a long tradition of adopting the dual system (half work, half study), were quickly able to adjust this balance to meet the technological challenges - and both countries are doing well as far as technological development is concerned. No wonder that VW in Germany is the single largest employer of vocationally trained bakers.

After all, the amount of formal training required of future employees by the high tech corporation will depend on the learning-intensive nature of the work performed there and the adequacy of the external supply of qualified workers. In times of transition, organisations like ISVOR might be necessary even for basic operational skills training. Whatever the solution, it certainly requires a high level of interaction between the firm and the suppliers of education and training, as well as high flexibility from the latter to adapt to the firm's changing needs. Most important, however, is the fact that in spite of its increased importance and visibility - learning by being told through formal education and training systems will increasingly become a very minor form of organisational learning.

Learning by doing is highly valued by learning organisations. In contrast to conventional production, experience in itself is no longer enough. Learning by doing is not synonymous with sitting by Nelly. The modern requirements of on-the-job training are a mixture of theory and practice: high tech tasks require relatively high levels of conceptualisation and abstraction.

One example, in the case of FIAT, was the carefully intertwined dual-system described earlier, which was designed for the training of operators. Relatively high levels of basic and technical education thus become the most important predictor of success of such training schemes. But specific technical knowledge is also important because critical skills such as diagnosing and decision-making are deeply embedded into concrete contexts, and are not generally transferred.

However, some basic skills are more easily generalised than others. For example, the principles of the scientific method (observation, hypotheses, testing and measuring, inference, etc.) can be taught and transferred to an array of situations. To make practical use of these skills in a production line, however, requires some knowledge of the machines, the mechanical or electrical systems to which this general knowledge will be applied. Dealing with mechanical or electrical machines will not, by itself, lead to the application of such general skills - if they were ever learned in a more general way. Practice alone is not enough.

Hence, one can note the importance of systematic training, and the increasingly teaching role of supervisors, as we see in the case of maintenance specialists coaching the newly ap-

pointed operators. The master in the medieval guild system and the skilled mastercraft in the modern corporation are being replaced by the manager of individual and group learning. The high tech craftsman has to rely more on the conceptual models of abstract thinking than merely on the imitation of professional role models. In fact, she/he needs new models to imitate.

Learning by visiting is an old way of learning which becomes vitally important to anticipating training needs, and to keeping up with latest developments. The visitor is like a bee in the business of cross-fertilisation. Consultants are a typical example of a mobile teacher - but who can only survive in the business if able to learn more from clients than he can teach them.

Today, the spy is being taught by his own victims - and they do it willingly. The emergent model of cooperation cum competition illustrated by cooperatives from Italy was also seen when Honda decided to engage in new ventures with Rover, and when IBM joined Apple to open up new windows for business.

In the past, and particularly in some academic circles and corporate rooms, information used to be most valued the less it was disseminated. Academics write papers most people can not understand, professionals become famous for developing such complex techniques that no one can use them. The less they were used, the more it would become famous. The same phenomenon ocurred in the shop floor. The best kept the secrets, the better for the organisation. This pattern is being disrupted - among other things by the speed of information flows. Technology imposed new evaluation criteria for knowledge held by people: learning is only useful if shared - and widely shared. Even clients should be more knowledgeable about products - after all only sophisticated buyers buy high tech products.

We describe the word "visit" here in a very broad sense, because it acquires a broad sense in the modern organisational practices. We present below some examples of the FIAT experience. One is the training of maintenance crews at the suppliers sites. In the case mentioned, suppliers sere not quite ready to provide such training - but it was possible to use the services of ISVOR to ease the transfer of learning. Learning with suppliers is a major challenge in the world of high tech. As discussed, this area still demands much improvement from both the supplier and the buyer of equipment. It is natural that the pressure to deliver equipment often leads to less than careful attention to training clauses. This is a classical dilemma of on-the-job training, which is further complicated by language barriers, lack of well-written manuals and poor planning of on-site traineeships.

Another example of learning by visiting was illustrated by the FIAT plant in Brazil. There, technology is at much lower stages - but the plant is clearly preparing itself to move into flexible manufacturing systems within the next few years. The constant - and not always easy - interactions, visits and organised internships of some engineers and technicians from the Brazilian plant to the Italian plants constituted a clearly effective mode of knowledge exchange. In some cases, the transfer was in the direction less expected - with the Brazilians offering suggestions and practical advice to their colleagues working in the more technological advanced plants. The reason is not that they are brighter than their Italian colleagues, but because less developed plants facing similar issues and working under similar standards have to develop more creative strategies to deal with the same problems. This same phenomenon was observed between Brazilian and German plants of VW (Bastos do Valle, op. cit), thus adding more credibility to the hopeful conclusions of Piore and Sabel (1985) concerning the relatively privileged situation of some N.I.Cs, to deal with new work technologies. These advantages lie mostly in organisational practices and in the flexible and creative use of human talents. Another area of organisational learning which reserves immense potential for high tech corporations.

Finally, and most important of all, learning organisations learn most by collectively reflect-

ing about what they do, and how to do it better. Reflective practice (Schon, 1983) literally becomes the daily food for thought of learning-intensive corporations.

The contrast with old practices is pertinent. In conventional operations, ten years of repeating a same activity very often does not lead to more learning or significantly higher efficiency - as illustrated by the learning curve: learning is fairly rapid in the beginning, and tends to stabilise. In fact, ten years of experience is often one year repeated 10 times. This is reflected in the slow growth of the productivity curse in these enterprises. Suffice to compare the slashing of the price of computers with that of automobiles, for example.

Learning required for high tech operations is not of a mechanical nature - and cannot be acquired simply through repetition and experience. These new types of learning required are heavily dependent upon organisational structures, career prospects, job design, incentive systems, organisational climate, and shop floor leadership. Learning occurs in formal and informal meetings where concrete problems or specific projects to improve quality or efficiency are discussed. Even though this is the cheapest and most effective of the four types of learning, it is the one which requires deeper changes in the organisational culture and management practices, since it requires broad participation, motivation and interest from virtually all workers. In fact, it is invisible, but depends on carefully designed and orchestrated organisational practices. The technological team led by the line technician that FIAT is trying to build up - an invisible college of permanent learning - is but one of the organisational design images of the reflective, learning-intensive corporation.

For the learning intensive, high tech corporation, the critical dimension is no longer its financial capital, or even its present level of technological sophistication, but its capacity to learn. Since it involves the liberation of human capacities. The sky is the only limit. Learning-intensive organisations are bound to reach there faster.

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